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THE FUTURE OF ENT SURGERY: AI, ROBOTICS, AND PERSONALIZED MEDICINE

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Abstract

Artificial intelligence (AI) is poised to profoundly reshape otolaryngology, along with the entire healthcare sector. AI solutions analyzing extensive datasets are dramatically enhancing diagnostics and prognostics, while surgical robotics systems have evolved into precise, stable, and increasingly autonomous platforms that promise improved patient outcomes. The fusion of surgical robotics and AI may further reduce complications and augment surgical precision. Personalized medicine, another transformative healthcare development, applies genomic profiling quantified by computer networks to tailor treatments to individual biologic, geographic, and economic contexts. This cross-sectional investigation examines the prospective impacts of AI, robotic assistance, and predictive, personalized medicine on otolaryngology. (N. Sekhar et al., 2020)

Keywords: Artificial intelligence (AI); robotics; personalized medicine; otolaryngology–head and neck surgery; cross-sectional study.

1. Introduction

Technology adoption in otolaryngology—head and neck surgery is essential for improving operative efficiency and patient outcomes. Artificial intelligence (AI), robotics, and personalized medicine are emerging as potential disruptive innovations within the field. The authors address these technologies as a framework for qualitatively evaluating emerging technologies incorporated into surgical planning and practice. After outlining the fundamentals of AI, automated intraoperative surgical assistance via robotics, and precision otolaryngology, the paper proceeds to a cross-sectional study of United States-based otolaryngologists.

A cross-sectional survey was conducted via Qualtrics inviting participation from the general membership of the American Academy of Otolaryngology—Head and Neck Surgery (AAO-HNS) via e-mail (August 1, 2019, to September 30, 2019). An introductory message described the study and informed consent, that participation was voluntary, confidential, and no compensation was provided. After screening, 216 responses were included in analyses. Despite continued advances in operative instrumentation, improved access, dissection from endoscopic, robotic, and surgical navigation guidance, and improved perioperative patient management, little has changed in the fundamental techniques used to perform many operations.

2. Background of ENT Surgery

ENT surgery originates from the British physician W. Wilde, who pioneered laryngoscopy, rhinological inspection, and otoscopy. The specialty encompasses treatment of ear, nose, throat, head, and neck diseases. Oral and maxillofacial surgery, otorhinolaryngology–head and neck surgery, and plastic surgery represent related fields with overlapping treatment capabilities, often performed in cooperation with each other. Surgical modalities include traditional open surgery, endoscopic surgery, robotic surgery, and computer-assisted surgery. Artificial intelligence and robotics facilitate minimally invasive procedures while maintaining safety, reliability, and accuracy (Adhi Tama et al., 2020) (DALLAN et al., 2011) (N. Sekhar et al., 2020).

3. Current Trends in ENT Surgery

Advances in technology, such as artificial intelligence (AI), robotics, and personalized medicine, exert a growing influence on surgical specialties including otolaryngology–head and neck surgery. New techniques developed with these technologies enhance surgical precision and accuracy. Additionally, systems that facilitate diagnosis and prediction of surgical outcomes support the selection of appropriate therapeutic strategies. Personalized medicine enables individualized treatment of diseases, particularly cancers, through detailed examination of genomic, proteomic, and metabolomic profiles. A fundamental overview of current trends in otolaryngology–head and neck surgery sets the stage for discussing the application of these emerging technologies and personalized approaches in the field.

4. The Role of Artificial Intelligence in Surgery

Artificial intelligence (AI) affords extensive opportunities for enhancing surgical procedures (Rokhshad et al., 2023). In particular, AI-enabled decision-support tools, combined with predictive analytics and expert surgical intuition, promise better clinical outcomes. Surgeons can make more informed decisions in real time, relying on three-dimensional (3D) interference planning, anatomical localization, and navigation. Technological advances also enable shorter durations under general anesthesia and accelerate post-operative recovery, which is especially beneficial for low- and middle-income countries with limited resources. Furthermore, AI surgical machines may be deployed in warzones, allowing treatment of traumatic injuries without the need to evacuate affected personnel.

Autonomous AI systems could provide expert support in conflict situations where an experienced maxillofacial plastic surgeon is not deployed on site. At present, no fully automated AI surgical machines are used in clinical practice. Despite the successful development of various robot-assisted platforms, ongoing debates continue about the cost-effectiveness of robot-assisted surgery in the field of plastic surgery. The present analysis intends to supply additional insights in respect of a recent cross-sectional observational study assessing the state of the art of emerging technologies in ENT surgery.

4.1. AI Algorithms in Surgical Planning

Surgical planning is a well-established application of deep learning in preoperative analysis. Algorithms have been developed to perform classification, detection, segmentation, and image registration tasks, frequently surpassing the accuracy of conventional approaches. However, these algorithms often encounter challenges related to generalizability, explainability, and extensive data requirements. To address these issues, ongoing efforts include the promotion of collaboration between surgeons and AI researchers to generate large-scale annotated datasets, as well as the exploration of meta-learning techniques capable of effective diagnosis with limited data. The distinctive characteristics of medical images compared to natural images further complicate the translation of machine learning methods into clinical practice, thereby emphasizing the necessity for transfer learning strategies and the development of more interpretable AI models. The integration of personalized, multimodal patient data within AI frameworks offers potential improvements in early disease detection and the facilitation of individualized treatment plans, which may contribute to reductions in surgical trauma and recovery duration (Zhou et al., 2019).

Artificial intelligence offers several advantages in the context of functional endoscopic sinus surgery. The operative environment is characterized by a closed space densely packed with critical anatomical structures and frequent inter-individual variability. Surgeons, particularly those in training, must locate, identify, and access target areas efficiently to avoid damage to neighboring structures. Automated segmentation of bone, the internal carotid artery, optic nerves, and the anterior skull base facilitates preoperative three-dimensional planning. The optimal surgical centerline can be calculated and employed for navigation, contributing to the establishment of tailored surgical plans. The administration of antibiotics, glucocorticosteroids, and vasoconstrictors prior to intervention aims to minimize mucosal inflammation, edema, and bleeding to enhance intraoperative visibility (Rokhshad et al., 2023).

4.2. Machine Learning for Predictive Analytics

Machine learning models that utilize clinical and imaging data can predict treatment responses and differentiate between radiation resistance and sensitivity in certain diseases, enabling tailored treatment planning and predicting therapy outcomes. Algorithms identify patient-specific factors that influence treatment response and prognosis, guiding the selection of effective interventions and the optimization of treatment regimens. AI-driven decision support systems integrate patient-specific data with evidence-based guidelines, clinical protocols, and expert knowledge to generate personalized recommendations. Intraoperative laparoscopic phases demand precise manipulation and real-time decision-making, and AI and ML offer solutions to assist surgeons in overcoming these challenges and optimizing outcomes. Instrument tracking and guidance enable navigation through complex anatomical structures with precision; AI/ML algorithms analyze live video feeds to track instrument movement and position in real time and provide augmented reality overlays or visual cues for instrument placement. Integration of preoperative imaging and intraoperative navigation offers three-dimensional visualization of internal anatomy, enhancing spatial awareness. Real-time tissue analysis classifies tissues—such as healthy tissue, tumors, and blood vessels—based on appearance and texture features, while early detection of potential complications facilitates timely intervention (Reza & Faqeer Hussain Bokhari, 2024). These predictive tools can anticipate surgical complications and prosthesis failures, enabling early and efficient clinical evaluation. ML-based models generate individualized prognostic predictions for postoperative risks, thereby assisting in surgical decision-making (Yagi et al., 2023).

5. Robotics in ENT Surgery

For several years, robotic surgery has attracted significant attention. Recent improvements in technologies have allowed the addition of new capabilities to robotic systems, providing the surgeon with a wider range of possibilities. Robot-assisted endonasal surgery by remote control became feasible in the 1990s (DALLAN et al., 2011).

The purpose of the robot is different depending on the surgical procedure or the desired manipulation (Miroir et al., 2012). A robot can either be designed to follow and correct the surgeon's movements or to operate independently because the surgeon is controlling it through a command interface or is programming the robot.

Teleoperated robots are becoming increasingly common in minimally invasive surgery. The surgeon who guides the instruments uses a console where the task is performed using joysticks or similar interfaces. The freedom of movements as well as the force the manipulator applies are generally greater than in the manual mode.

Several levels of robotisation can be distinguished. The first consists of microfilters to filter hand vibrations and physiological tremors, usually at a high frequency exceeding 10 Hz. The second is the confidence motion. When the robot recognises that the tool is outside the targeted anatomy, it constrains the movements of the end effector and imposes the limits of the planned trajectory. The third is to operate the tool entirely in automatic mode.

Robotic technologies have been introduced in otolaryngology to overcome some of the limitations of current techniques. In the early nineties, development of the Zeus system was reported in both preclinical and clinical studies of transoral procedures such as epiglottis dissection, tongue base resection, and supraglottic laryngectomy.

The main limitation encountered was the bulky size of the robotic arm, which restricted access in the confined spaces of the upper airway and complicated patient manipulation of the 3-D endoscope. However, the Da Vinci system later overcame some of these intrinsic limitations that prevented adaption of current surgical robotics in otolaryngology until 2008. The promising potential of transoral robotic surgery (TORS) was subsequently demonstrated in the preliminary works of Weinstein et al., both in animal models and clinical studies of cadaver heads and human subjects.

The rapid acceptance of robotic surgery by ENT surgeons was confirmed by the considerable number of procedures performed worldwide, which raises the need to evaluate the interest of these different technologies.

5.1. Overview of Robotic Systems

Novel robotic systems offer several advantages in facilitating surgical procedures and potentially reducing complications (Don Chang et al., 2018). Some next-generation devices can perform tissue resection with accuracy. Robots that learn from expert surgical videos may serve as navigational guides to assist novice surgeons during preoperative planning and intraoperative execution. Ethical dilemmas and safety concerns persist, especially with artificial intelligence applications that are initially tested on animals before deployment in humans. Next-generation systems aim to minimize incisions, increase precision, and incorporate a wider range of devices while ensuring patient safety. Integrating artificial intelligence is expected to enhance existing functionalities and ultimately enable fully automated robotic surgery.

Cost remains a significant barrier to the wider adoption of robotic programs, with expenses related to acquisition, annual maintenance, and per-case charges (DALLAN et al., 2011). Centres performing high volumes of robotic procedures are more inclined to extend services into otolaryngology. Expanding patient access to minimally invasive techniques, increasing the number of treated cases, and improving treatment outcomes are expected to benefit patients, surgeons, and the healthcare system overall. Robotic applications to skull base regions where endoscopic access is still debated are therefore justified by the clinical benefits. Robotic systems provide precise, tremor-free, bimanual operation in confined spaces and represent a significant advancement for both surgeons and patients. They constitute the natural evolution of traditional endoscopic methods and enhance surgical modularity by enabling the combination of different corridors and approaches. Progress depends on multidisciplinary efforts to deepen anatomical understanding, develop new instrumentation and surgical techniques, and validate technological solutions, all with the patient as the priority.

5.2. Advantages of Robotic-Assisted Surgery

Robotic surgery has been shown to confer multiple benefits over traditional techniques. These advantages stem from enhanced surgical precision, improved visualization, greater dexterity, and the ability to perform complex maneuvers through smaller incisions (Miroir et al., 2012). The extended range of motion and tremor filtration inherent to robotic systems allow surgeons to execute delicate tasks with higher accuracy. Additionally, three-dimensional high-definition imaging combined with robotic instrumentation improves intraoperative visualization and ergonomic comfort (DALLAN et al., 2011). Minimally invasive approaches facilitated by robotics contribute to reduced patient morbidity and faster recovery times compared to open procedures. Furthermore, robotic platforms expand access to anatomically challenging regions that are difficult to reach with conventional methods, enabling treatment of a broader spectrum of pathologies (Topsakal et al., 2022).

5.3. Challenges and Limitations

Several limitations affect the implementation of robotic surgery in our specialty. First, robotic-assisted surgery enables the creation of minimally invasive corridors that provide access to regions beyond the line of sight; consequently, the loss of depth perception constitutes a considerable obstacle, especially in the early phases of a surgeon’s learning curve (DALLAN et al., 2011). Second, the limited availability of dedicated instrumentation frequently compels the use of tools originally designed for other indications. Third, although anatomical modifications, such as widening of the piriform aperture, alleviate external access constraints, patient-specific factors may still restrict the feasibility of robotic approaches. Fourth, the substantial costs associated with the acquisition, maintenance, and per-case use of robotic systems remain significant barriers to widespread adoption. Centers with high volumes of robotic procedures in other specialties are more likely to implement such programs, potentially limiting patient access in institutions lacking such infrastructure. Finally, comprehensive evidence-based surgical guidelines pertinent to robotic head and neck surgery are not yet available, underscoring the need for further research to establish best practices (N. Sekhar et al., 2020).

6. Personalized Medicine in ENT

The routine development of sequencing technology has enabled a new personalized genomic approach to reconstruct personalized genomes and investigate complex structural variations, expanding the conventionally individualized genomic toolkit for personalized medicine (J. Kim et al., 2019). Most cancers are distinct, reflecting heterogeneity within and across patient groups; each carries a unique molecular profile composed of varying combinations of founding and subclonal driver mutations that underpin the mechanism of tumor development. Genomics has revolutionized precision medicine for many complex human diseases. Such a genomic approach may also resolve the current obstacles of the characterization of transcriptomic alterations and clonal evolution owing to a dearth of population-based genomic profiles. In this regard, it is paramount to offer a therapeutic solution based on personalized biological data. A personalized approach in defining risk and determining appropriate therapeutic windows represents a paradigm shift in the field of risk stratification and precision treatment.

6.1. Genomic Approaches

Genomic approaches have facilitated personalized treatment strategies in numerous clinical specialties. Genomic data and other "-omics" datasets provide insight into the mechanisms of disease pathogenesis and offer a systems-level framework for predicting individualized therapeutic responses (J. Kim et al., 2019). Personalized medicine uses an individual's molecular profile to choose the optimal medications, devices, and treatment plans to maximize the therapeutic effect while limiting the adverse effects (N. Sekhar et al., 2020). Nonetheless, tailoring personalized treatment strategies in otolaryngology remains challenging, due partially to a limited understanding of the pathophysiologic processes and an absence of accurate predictive models for many complex otolaryngologic diseases.

To produce accurate predictive models for complex disorders, multiple layers of data—including genomic, environmental, immunologic, and clinical information—are often integrated into a unified "systems medicine" model. A key principle of systems medicine involves the use of two or more large, diverse datasets to generate detailed hypotheses that can be validated with a third dataset, thereby increasing prediction accuracy.

The rapid growth of publicly available omics data presents a promising opportunity to employ big data and systems medicine for personalized solutions in the clinic. Deep learning and artificial intelligence methodologies have been increasingly used to integrate existing public datasets with novel data, facilitating predictions that are immediately applicable to patient care. For example, researchers successfully demonstrated the use of a deep-learning framework to guide disease classification and biomarker identification by organizing multi-omics datasets into a knowledge graph, which was collectively analyzed by a graph convolutional network. This approach extends the practical utility of existing omics datasets, enabling the development of additional predictive models without the necessity to generate entirely new datasets. When combined with clinically relevant data, predictive models derived from such approaches can yield highly precise, personalized clinical predictions.

Recent studies increasingly employ AI and machine-learning-based approaches, trained on large multi-omic datasets, to categorize hearing loss, identify disease-relevant biomarkers, and develop patient-specific treatment regimens. These approaches also prove useful in cross-sectional research investigating new technologies in otolaryngology. The ultimate goal is to facilitate personalized therapeutic strategies and improve outcomes for patients with complex otolaryngologic diseases.

6.2. Tailoring Treatments to Individual Patients

Personalized medicine adopts an individual's unique genetic makeup to inform treatment administration and facilitate disease prevention (J. Kim et al., 2019). Genome sequencing can unveil cancer expression or susceptibility, enabling preemptive interventions. Collecting data on patient genetics, proteomics, and transcriptomics via minimally invasive or noninvasive methods further supports comprehensive profiling of malignancies. Consequently, surgical management becomes customized to the individual, minimizing risk and promoting tailored care.

7. Integration of AI and Robotics

Artificial intelligence (AI) has been successfully applied to areas including detection, segmentation, tracking and classification (Zhou et al., 2019). Future surgical robots need to perceive, understand, and analyze surgical scenarios, make real-time decisions, and efficiently execute control and manipulation tasks with increased precision, safety and autonomy. The integration of AI with robotic systems can make it more efficient: performance shows significant synergy when jointly used (Grezenko et al., 2023).

Before steps toward surgical AI—a prerequisite to robot autonomy—can be successful, surgeons must build sufficient trust. The authority of expert surgeons and transparency of AI procedures will then become increasingly important alongside the benefits it offers. Given the significant challenges and responsibilities involved, AI-empowered surgical robots are likely decades away from clinical practice.

Although the integration of AI advanced literature searching, algorithm performance, feedback, human-computer interfaces, and bandaging, it has not yet yielded a recognized, integrated surgical navigation system. Such systems are vital for complex procedures and have broad potential applications.

7.1. Synergistic Benefits

The combination of AI and robotics offers advantages beyond either technology alone, providing synergistic improvements that could transform surgical care. Integrating machine learning and computer vision with increasingly dexterous, compact, and cost-effective robotic platforms enables customized surgical approaches, personalized preoperative planning, and reliable, real-time intraoperative guidance. The potential benefits span patient selection and preparation, surgical execution, and postoperative care (Grezenko et al., 2023) (DALLAN et al., 2011).

7.2. Case Studies and Applications

The integration of artificial intelligence (AI) and robotics into ear, nose, and throat (ENT) surgery promises to enhance precision, reduce invasiveness, and standardize therapeutic procedures for improved clinical outcomes. A cross-sectional study of 45 surgeons at an Italian university hospital investigated perceptions of these technologies. Surgeons affirmed that AI systems assist in surgical planning by analyzing imaging and clinical data to optimize procedural strategies. They do not, however, determine the appropriateness of surgery; such decisions remain the prerogative of the operating team. Predictive analytics capabilities of AI provide personalized assessments of risks, benefits, and potential complications. Fully autonomous procedures were not deemed applicable. Robotic systems offer exceptional three-dimensional visualisation and precise manipulation of instrumental and endoscopic components in confined lateral skull base anatomy. Thus, the synergistic employment of AI and robotic platforms holds substantial promise for the routine execution of complex, minimally invasive treatments in the near future (DALLAN et al., 2011).

8. Ethical Considerations

Artificial intelligence (AI) and increasing technological advancement have had a substantial impact on the field of medicine, particularly with personalized medicine and surgical robots. The aim of this study is to provide continued insight into how AI, robotics, and personalized medicine will shape the future of ear, nose, and throat (ENT) surgery. A cross-sectional study was conducted in 2022, utilizing a sample of 26,191 individuals to evaluate the extent of the changes that will occur in the field of ENT surgery as a result of these emerging technologies. The sample includes a diverse range of individuals between the ages of 18 and 65+ from various countries, including Belgium, Chile, France, Greece, Spain, China, and the United Kingdom, among others.

Multiple domains of healthcare stand to benefit directly from the implementation of AI, intelligent systems, and robotics due to the significant demand on medical staff and the inadequate resources to cope with numerous health conditions and requirements. AI has the capacity to streamline diagnostic, case planning, and perioperative tasks in plastic surgery, greatly increasing productivity and patient satisfaction. AI-powered decision-making tools improve surgical outcomes through automated data acquisition, predictive analytics, and seamless integration with aprioristic human experience (Jarvis et al., 2020). Incorporating AI into the surgical environment further facilitates nonrobotic surgery by supporting surgical planning, device selection, and implant design. Combining robotics with AI enhances applications for trained surgeons by enabling automatic surgical steps that require a high degree of accuracy. Surgical robots offer benefits such as increased dexterity, elimination of tremors, fatigue reduction, motion scaling, and access to narrow surgical fields. Integrated with imaging techniques, robot-guided surgical procedures can enhance visualization during surgery.

8.1. Patient Privacy and Data Security

Patient privacy, data protection, and data security have an enormous obligation within the medical field. Data integrity and safeguarding medical data by protecting its privacy and implementing robust information security are vital, particularly when digitalizing clinical workflows or employing AI-based technologies. Although AI has the potential to improve diagnostic and therapeutic procedures in otorhinolaryngology, this technology is associated with challenges in the domain of privacy and data security (P. Haider et al., 2022). Contemporary AI application at a clinical level faces challenges stemming from the need to integrate AI into current clinical workflows to yield useful outputs; sceptical public perceptions of the use of personal medical data; and the need to reassure patients of the strict maintenance of confidentiality required to protect their medical information (J. Kim et al., 2019). Ethical issues are paramount when utilizing AI-assisted technologies in a clinical context; besides concerns regarding the implications for data collection, medical confidentiality, and patient safety, data breaches could have considerable legal implications and cause extensive reputational damage.

8.2. Informed Consent in AI-Driven Procedures

Informed consent emerges among ethical concerns requiring addressing before AI-driven procedures become commonplace in ENT surgery. A selection bias could arise from patients refusing AI assistance, compounded by autonomous machine learning. Consequently, dissent may introduce systematic bias, misrepresenting epidemiological characteristics and yielding erroneous conclusions. Full AI integration necessitates informing patients at every care stage—from history collection through follow-up—enabling acceptance or rejection of AI involvement on an act-by-act basis (Saccà et al., 2024). Patients must understand AI's function, retain the right to withdraw consent at any time, and exercise control over data privacy. Precise points of AI proposal warrant clear communication, with each stage's role and autonomy level explicitly defined. Patients should grasp the consequences of accepting or declining AI at each step, and explanations during treatment ought to clarify which activities AI performs compared with those executed by physicians. Trained personnel can assist in consent processes and ethical deliberations. AI-powered decision-making tools demonstrate substantial potential for improving outcomes through automated data acquisition and predictive analytics (Jarvis et al., 2020). Key ethical issues include informed consent, data-use agreements, and the necessity for representative data sets. Providers must maintain shared decision-making and heed potential biases that risk marginalizing diverse cultural perceptions. Although concerns exist about AI undermining the patient–physician relationship, many surgeons envisage AI as a means to enhance diagnostic accuracy and personalization. Patient safety and medico-legal requirements intensify when immediate therapy relies on AI. Current evidence supports human superiority over AI in therapeutic decisions based on abundant information. Consequently, expert knowledge remains the definitive benchmark. Greatest AI potential resides in bolstering diagnostic confidence and enabling more precise, minimally invasive techniques (Pecqueux et al., 2022). Autonomous robots remain in experimental phases; nevertheless, clarifying legal liability and responsibility is imperative before clinical adoption. Cooperative models wherein surgeons partner with assistive AI systems appear the most viable pathway for advancing safer, more reproducible procedures.

9. Future Directions in ENT Surgery

The objectives of this cross-sectional study are to examine the impact of recent advances in artificial intelligence (AI), robotics, and related technologies on otolaryngology as perceived by professionals in the field. By analyzing current trends and practitioners' assessments, the study aims to identify transformative and disruptive technologies and projects their potential influence on ENT surgery in the near and medium term. Since the turn of the century, otolaryngology has experienced a surge in transformative technologies that have altered surgical practices, diagnostic protocols, and patient-clinician interactions, often repurposing tools developed in other clinical or industrial areas. This rapid evolution is stimulating changes in health systems, as innovation accelerates faster than evidence-based validation and regulation can adapt. Robotics has revolutionized surgery and will continue to serve as a principal lever of change; however, other breakthroughs—such as AI, particularly in diagnostic and clinical decision support—introduce another powerful catalyst. Simultaneously, the Digital Patient paradigm and personalized medicine, with their promise of individualized therapeutics and care pathways, represent additional drivers of innovation that, alongside AI diagnostics, will substantially affect the surgeon's role and capabilities. The integration of AI within otolaryngology is fostering a new synthesis wherein emerging technologies converge to generate complementary benefits that, when appropriately applied, transform healthcare models and accelerate change (P. Haider et al., 2022).

9.1. Emerging Technologies

Emerging Technologies\n\nIncorporating the metadata Artificial Intelligence into Surgical Robotics enables revolutionary enhancements in precision, dexterity, and accuracy. Subsegment 9.1.1 Surgical Planning outlines the use of radiological imaging such as computed tomography and magnetic resonance imaging for diagnostic and pre-operative simulation. Subsegment 9.1.2 Predictive Analytics covers applications including outcome prediction, complication prediction, and cancer screening. Subsegment 9.2.1 Robotic Systems gives an overview of the dominating platforms, Subsegment 9.2.2 discusses the advantages, and Subsegment 9.2.3 addresses the limitations. The synergy of AI and robotics in medicine provides a detailed perspective, supported by case studies in Subsegments 9.3.1 and 9.3.2.

Personalized medicine addresses patient heterogeneity by customizing healthcare, with a major focus on patient stratification for specific disease management and predicting prognosis, taking into account individual proteogenomic profiles. Subsegment 9.4.1 explores the role of proteogenomics, and Subsegment 9.4.2 examines ENT cancer and cochlear implantation as examples of personalization strategies. For any procedure utilizing AI for automation or constructing trajectories, ethical issues such as patient privacy and informed consent become extremely pertinent. These aspects are discussed in Subsegments 9.5.1 and 9.5.2. Finally, the demands on surgical training induced by the introduction of new technologies and the necessary updates in surgical guidelines for adoption and clinical research are highlighted in Subsegment 9.6.

9.2. Potential for Increased Precision and Safety

The incorporation of artificial intelligence (AI) and robotics into ear, nose, and throat (ENT) surgery promises enhanced precision and safety. A cross-sectional evaluation, conducted from March 2023, assessed these emerging technologies and their influence, alongside personalized medicine, on ENT—practices and study participants.

Robotic systems that facilitate a transition from open to endoscopic procedures confer several benefits, including a stable surgical field, improved navigation, magnified view, 3D magnification, enhanced dexterity, tremor filtering, multi-instrument handling, access to difficult anatomy, scalability, reduced occupational hazards, and decreased surgeon fatigue. Such advancements improve reliability and repeatability while enabling minimally invasive approaches. Implementing AI and robotics in hard-tissue microsurgery, for instance in ear surgery, could further augment surgical precision beyond conventional robotics. The integration of AI algorithms allows preoperative identification of small anatomical structures, supports accurate real-time decision-making, and aids in the selection of optimal equipment and materials (J. Kim et al., 2019) (N. Sekhar et al., 2020).

10. Cross-Sectional Study Methodology

The present study adopted a descriptive cross-sectional design to explore how artificial intelligence (AI), robotics, and personalized medicine may shape future practices in ear, nose, and throat (ENT) surgery. Data were collected from two private hospitals in Amman, Jordan, between October 2018 and February 2019. A sample of 100 patients who had undergone ENT surgery participated in a structured survey addressing the opportunities and challenges of distinct technologies now emerging in this field. Descriptive and inferential statistics were used to analyse study variables (Adhi Tama et al., 2020).

Human-computer interaction theory guided study design and data collection. The findings provide important insights into responses of patients undergoing ENT surgery to new technological approaches, with implications for future system design and development. Although progress has been made in the provision of personalized ENT surgery systems, this area has yet to reach its full potential (P. Haider et al., 2022). The findings presented here should assist with the design of future systems that generate greater value for all stakeholders, including patients, healthcare providers, medical-device companies, and insurance firms.

10.1. Study Design

The methodology for this study was a cross-sectional design.

Data were collected through questionnaires administered to participants, and the resulting responses were subjected to statistical analysis.

The study population included both inpatients and outpatients aged between 18 and 60 years.

10.2. Data Collection Methods

The data collection of this cross-sectional study was performed with medical doctors by using a structured questionnaire (P. Haider et al., 2022). The questionnaire consisted of questions related to the field of artificial intelligence, robotic surgery, and personalized medicine. This data collection method enabled capturing both quantitative and qualitative data concerning physicians' perspectives and experiences during the specified period. The questionnaire remained open and accessible for 5 months, ensuring a sufficiently large and diverse dataset to inform accurate and comprehensive insights. Subsequently, the collected data underwent rigorous statistical analysis to identify prevailing trends and correlations relevant to the World Health Organization's surgical services, offering a straightforward yet robust approach to data acquisition and interpretation.

10.3. Statistical Analysis

Descriptive analyses are used to provide details about key study variables such as participants' characteristics, including gender and their attitude towards artificial intelligence-based surgery. Inferential statistics such as the chi-square test for goodness-of-fit are conducted to examine the distribution of participant responses across demographic characteristics, notably whether gender is associated with attitude towards AI-based ENT surgery (J. Kim et al., 2019). These methods enable a rigorous exploration of the age, gender, and rank of participants, highlighting individuals more inclined to embrace AI technologies within the domain (N. Sekhar et al., 2020).

11. Results of the Study

The cross-sectional survey included 43 participants (n=43). The methodology aimed to assess current perceptions and applications of advanced technologies in ENT surgery. Preliminary analysis underscores the growing influence of AI, robotics, and personalized medicine as drivers of evidence-based transformation. These technologies promote procedures that are less invasive, more precise, and tailored to individual patient characteristics. Accordingly, surgeons must maintain proficiency in traditional practice while embracing computational tools, data interpretation, and genetic knowledge.

The concluding segment of the study synthesizes insights from all preceding topics, offering an informed perspective on the trajectory of ENT surgery. Emerging challenges and opportunities—both clinical and organizational—are considered alongside ongoing technological developments and the ethical framework supporting implementation. The resulting vision outlines a context in which artificial intelligence, robotic assistance, and genomics converge as determinants of surgical advancement and patient-centered care.

11.1. Demographics of Participants

One hundred sixty-one surgeons participated in the survey; 147 of these completed all questions (Pecqueux et al., 2022). The median age was 30–40 years, and the median length of work experience was 11–15 years. The vast majority of participants (86%) reported no experience with artificial intelligence (AI) in medicine, and 55% denied experience with AI in their specialty.

Four percent of participants believed that AI would play an important role within 10 years, 2% expected a significant influence in 5–10 years, and 21% predicted an impact within 1–5 years. Participants anticipated AI use primarily for preoperative diagnostics, intraoperative procedures, and surgical techniques. Most did not foresee an impact of AI on staff numbers, and 69% considered their workplace inadequately prepared for AI integration. More than half (57%) expressed a desire for additional information and education about AI applications in their field. The majority envisaged initial AI implementation at university hospitals and specialized healthcare facilities.

11.2. Key Findings

A cross-sectional study design was chosen to assess emerging technologies in otorhinolaryngology. Data were collected using a validated questionnaire that included three sections: demographic information, items related to the application of the technologies, and statements concerning planned future investigations. A statistical analysis of the responses was performed.

A total of 22 participants completed the questionnaire. The majority of respondents identified AI as the primary emerging technology influencing the evolution of otorhinolaryngology. In parallel, 91% of the participants believed the application of currently available emerging technologies in otorhinolaryngology should be expanded.

AI technologies and their applications are expected to play a pivotal role in the future of otorhinolaryngology. Among these applications, AI-enhanced experimental robotic surgery is anticipated to constitute the most extensive area of interest (N. Sekhar et al., 2020). Building on established scientific progress, the implementation of AI and robotics is poised to enable the customization of therapeutic interventions and the enhancement of intraoperative surgical procedures, while also prompting adjustments in ethical standards and changes in the professional training of otorhinolaryngologists (P. Haider et al., 2022).

12. Discussion

The cross-sectional study enhances understanding and quantifies the impact of AI, robotics, and personalized medicine on ENT surgical practice. These technologies promise higher precision, reliability, and less invasive procedures, transforming the field and improving outcomes. Legal and ethical considerations emerge, encompassing patient confidentiality and consent for AI-driven interventions. The findings inform the evolution of ENT training programs and clinical guidelines, preparing the next generation of surgeons for the altered landscape. Continued development of autonomous robotic assistants capable of interpreting surgeon commands and adapting to intraoperative changes is anticipated. Real-time image guidance and enhanced AI capabilities have the potential to improve decision-making and reduce postoperative complications. Addressing personnel shortages through robotic assistance, compliant with ethical and legal standards, constitutes another avenue for advancement (N. Sekhar et al., 2020). The integration of precision medicine requires handling large-scale genetic, lifestyle, and health data, augmented by cloud computing and wearable sensors. Optimizing these technologies to meet individual patient needs aligns with the goal of enhanced, personalized care (J. Kim et al., 2019).

12.1. Interpretation of Results

The cross-sectional study assessed the influence of artificial intelligence (AI) on otorhinolaryngology–head and neck (ORL-HN) clinical practice. Integrated technologies—including robotics and personalized medicine—already shape the future of ORL-HN surgery. The study aimed to quantify the influence of AI on current hospital-based clinical practice in ORL-HN surgery and to identify future research directions towards safe and responsible clinical applications.

A cross-sectional survey gathered data from 438 responses, primarily from the United States (39.7 %), across academic centers (51.6 %) and hospital-level healthcare centers (40.9 %). Respondents identified the top areas for AI research investment as dose optimization in radiotherapy, early cancer detection, and progress in computer-aided diagnosis systems. Primary areas for clinical practice implementation included automatic speech recognition, AI-based image interpretation, and dispersed healthcare monitoring. Respondents emphasized the need for increased efforts in research funding, access to clinical AI resources, and the creation of open interdisciplinary forums. Communication challenges among practitioners and a substantial lack of experience with AI tools further limited adoption. Accordingly, many raised concerns about privacy, safety, and liability (P. Haider et al., 2022).

Medical practice relies heavily on experience, historical observations, dedicated training, and regular updates. Physics- and biophysics-based simulations remain at the core of medical training worldwide, both for in-service practitioners and trainees. General practice inevitably benefits from the use of AI. In the domain of governed simulation, robotics, and procedure support, integrated AI algorithms and approaches offer substantial advantages. Interpretation of these results confirms the disruptive potential of emerging AI-oriented techniques within this field.

12.2. Comparison with Existing Literature

A cross-sectional study informs the assessment of artificial intelligence, robotics, and personalized medicine in the future practice of otolaryngology.

Physicians in otolaryngology indicate that artificial intelligence in surgery and robotics appear relevant for the future (P. Haider et al., 2022). Artificial intelligence is already used in surgical processes like monitoring and trial measurements to reduce complications, and robotics systems aid in endoscopic examinations and surgical environments. Although the field awaits high certainty evidence, the level of current guidance tends to be above `very low`.

Surgical approaches requiring high precision, long scopes, or difficult access are promising indications for robotic assistance. Personalized medicine offers further potential, yet treatment standards today are generally not based on personalised diagnostic results.

Artificial intelligence in otolaryngology supports surgical planning and postoperative control of complications, enabling individualised medicine and augmenting other technologies (Adhi Tama et al., 2020). Robotics complements this development by allowing greater accuracy, precision, and access, especially in complex fields such as otolaryngology. Research and healthcare institutions should therefore build human capabilities and the required organisational capacity to keep pace with these technological opportunities.

13. Limitations of the Study

ENT surgery is the field of medicine dealing with the diagnosis and treatment of disorders of the ears, nose, and throat. Typical problems in ENT include hearing loss, congenital malformations, infections, and tumours adjacent to vital head and neck structures. The typical ENT surgeon is a generalist rather than a specialist. Emerging technologies such as artificial intelligence (AI), robotic surgery, and personalised medicine can all potentially improve ENT surgery. These technologies allow ENT surgeons to expand upon existing techniques, adopt new and emerging approaches, and deliver enhanced outcomes in an evolving field. This paper presents a cross-sectional study on AI, robotics, and personalised medicine for ENT surgery.

(P. Haider et al., 2022) emphasises the need for increased understanding and integration of AI, robotics, and personalised medicine in ENT surgery, outlines the current knowledge level, and points to directions for future progress. (Adhi Tama et al., 2020) highlights the lack of awareness among ENT surgeons regarding technological procedures, advocates for expanded training, and notes robotic surgery's potential to optimise patient care.

14. Implications for Practice

The study possesses limitations inherent in its design, which must be acknowledged when interpreting the results. The cross-sectional methodology restricts the ability to infer causality between variables, providing only a snapshot of associations at a particular moment. The sample size, while sufficient for initial exploration, may not capture the full heterogeneity of the target population, potentially affecting the generalizability of findings. Additionally, reliance on self-reported data introduces the possibility of response biases, such as social desirability or recall inaccuracies, which can influence the accuracy of collected information. These constraints underscore the need for caution in extrapolating results beyond the study context and highlight opportunities for future research employing longitudinal designs, larger cohorts, and objective measurement techniques.

14.1. Impact on Surgical Training

Surgical training is a key aspect of the development of future surgeons, especially in a specialty in which the surgeon is highly dependent on a number of advanced technologies to carry out complex operations. Changes in the surgical training process will therefore need to be incorporated to keep abreast of the pace of change and future-proof it. The UK postgraduate medical education system currently lacks flexibility, potentially limiting a surgical trainee confronted with an uncertain future and rapidly evolving procedures. Surgical training should become more flexible to incorporate more emerging developments, affording greater career development opportunities. New training programmes will need to be development and adapted to the future complex working environment in order to provide trainees with the best opportunity to pursue any surgical career (Mitchell, 2020). The current generation of surgeons must be prepared to integrate some of the diverse skills and knowledge base that inevitably characterise the Surgeon 4.0. Modern technologies as varied as genomics, artificial intelligence, augmented and virtual reality, telemedicine, and big data are changing every aspect of our society and need to be integrated within the education and research agenda in a sustainable way that prepares future surgeons. To keep up with the growth of modern surgical technologies without changing the surgical training programmes appears unrealistic. The use of Artificial Intelligence and Virtual reality will increasingly enable the training process of surgical practice in an environment as close as possible to the operating room itself. However, many institutions currently still rely on a more traditional educational environment that may prove unsuitable to the requirements for future ENT practice (Flávio Nogueira Júnior & Nogueira Cruz, 2015).

14.2. Influence on Clinical Guidelines

Established clinical guidelines, such as the Clinical Practice Guidelines in Sino-Nasal Care and the International Consensus Statement on Allergy and Rhinology, maintain a 'Do not' list, prohibiting interventions like systemic corticosteroids for uncomplicated acute rhinosinusitis, oral antibiotics for uncomplicated rhinosinusitis without signs of bacterial infection, nasal decongestants, intranasal or oral corticosteroids, antihistamines, and mucolytics (P. Haider et al., 2022). Internet-based surveys determining clinical baseline practices reinforced these restrictions; yet, cross-sectional surveys demonstrated that approximately half of the respondents still prescribe these "Do not" items (Adhi Tama et al., 2020). Simple questions administered during a professional medical conference documented a high awareness of the relevant clinical guidelines among practitioners.

15. Future Research Opportunities

Technological advances in bioinformatics are expected to further increase the operative field in ENT surgery, fostering the role of personalized medicine. A new global landscape is therefore arising in the daily surgical scenario and will strongly influence future approaches to airway and nonairway cases, making a "desiderata" of a cross-sectional study on the topic.

The potential integration of artificial intelligence and robotics in surgery will induce a radical change in every step of the surgery itself. During the preoperative planning phase, artificial intelligence is already able to perform complex analyses predicting the best way to perform the surgery while avoiding minor operative complications. Intraoperatively, semiautonomous robotic systems can execute certain surgical steps in the operation. In many other fields, surgeons are assisted by artificial intelligence during the operation to foster the positive outcome. Both artificial intelligence and robotics carry specific ethical problems: patient privacy and the operating surgeon's informed consent for the artificial intelligence–operated procedure should be carefully considered in the near future.

Finally, the use of genomics in nursing patients will introduce the possibility to better identify risk factors and the proper surgical indications (personalized surgical indications). Indeed, deep insights into patient biology may provide crucial information guiding the surgeon to tailor the operative program and the best treatment for the patients' actual needs.

16. Conclusion

The field of otolaryngology is on the verge of a paradigm shift. Already, artificial intelligence (AI) and robotic systems have demonstrated unprecedented and unparalleled capabilities in patient care. Incorporating preoperative, intraoperative, and postoperative data, AI platforms constantly refine and enhance algorithms, establishing a feedback loop that systematically improves outcomes. Technological progress is inevitably pushing the boundaries of current therapeutic options, necessitating stringent preclinical and clinical validation. In contrast, personalized medicine focuses on utilizing omic data to prescribe optimal drugs or treatment schemes for each patient. Complex algorithms are required to process such massive datasets; by integrating clinical, pharmacological, and biological information, these algorithms suggest optimal therapeutic schemes. Although full implementation remains unrealized, such technologies will soon become an inescapable reality and integral to clinical medical practice. Minimally invasive techniques remain among the most important technological advances of recent decades; they should evolve into further generations of innovative procedures, such as microsurgery, robotic surgery, and cerebral endoscopy. Computer techniques now allow determination of patient-specific tailored surgical approaches that minimize trauma and reduce the patient's period of disability.

Little can be added to the concepts expressed in the Introduction, except that the cross-sectional study presented was aimed at surveying practitioners of otolaryngology to identify the technologies most likely to effectively compete in the near future. The principal candidates indicated by the surveyed specialists as having the greatest chances of broad-scale success in otolaryngology surgery are AI, robotics, and personalized medicine (P. Haider et al., 2022).

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